Global Supply Chain design with integration of Transfer Pricing
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Chapter 1

Introduction

The process of establishing a manufacturing and distribution network represents a major challenge for the companies. Supply chain management is the management of the links between an organization and its suppliers and customers to achieve strategic advantage. Therefore Supply chain management is all about having the right product in the right place, at the right price, at the right time and in the right condition.

Business has achieved global dimensions where manufacturing activities of a distributed product are dispersed through many locations and the design and management of global supply chains are nowadays one of the most active research topics in global logistics. Global supply chain management involves international considerations rather than simply local or national considerations as in supply chain management. Transferring commodities produced from one country to another could be difficult to manage. First the company will consider all traditional supply chain operation factors such as sourcing, manufacturing and distribution costs, capacities and tax costs. Additionally, the firm will incorporate the potential impact of intra-company internal prices (transfer prices) between different countries and entities on this network.

With a good distributed product strategy, globalization give opportunities and advantages in terms of low production costs and tax advantages offered by some countries. In this case the intermediate products play a key role in global supply chain design projects. For instance, we may have a situation where the distribution of the final product is kept close to customer while the components or semi-finished products are transferred towards different sites in different countries. In this situation the components and semi-finished products are manufactured in different centers, the finished product is manufactured in facilities located in different countries and the distribution centers are located close to the external markets. The number of alternatives is very large and the optimal configuration cannot be known in advance but is determined by a model. This model takes into consideration usual conditions like capacities and operational and transportation costs that are expected to impact on the supply chain decisions. Then the mathematical optimization model provides decision support and guidance in terms of constructing a supply chain network from a wide range of sourcing, manufacturing and distributing alternatives in different countries. Thus, the company can identify and propose the best production and distribution option as the mathematical model generates the optimal supply chain to sat-
isfy the market demand forecast and maximize the firm’s profits. The model includes a description of how the selected production and distribution activities collectively link together to form this supply chain.

But, as one of the main motivations is to take profit of the financial and tax advantages offered by some countries, it is of major interest to combine transfer pricing and operations decisions. With this strategy multinational firms are able to apply efficient tax planning across group entities and they have the incentive and opportunities to engage in tax avoidance. For instance, global companies have the opportunity to reduce corporate taxes by locating operations in low-tax jurisdictions, by shifting income from high-tax jurisdictions to low-tax jurisdictions, and by exploiting variations in the tax rules of different countries. And here is where intermediate products gain such importance, because intermediate and final products can be shifted between the different subsidiaries of a global company with an established price for the exchange. Taking into consideration that the involved subsidiaries are located in different countries, transfer price is a powerful tool for shifting income to subsidiaries in low-tax countries and consequently increasing the global after tax profit of the company. Therefore, multinational firms tend to be more successful in avoiding corporate taxes than local or national companies as they are able to achieve economies of scale in tax planning through the use of their extensive operations and inter-firm commerce.

A transfer price is the price that a selling department, division or subsidiary of a company charges for a product or service supplied to a buying department, division or subsidiary of the same firm. This definition could be extended to include the transfer between collaborating companies within the same manufacturing network. In such cases, the transfer price is the value of the product when crossing international boundaries, but this model only considers a single company with different divisions or subsidiaries located in different countries. With companies of this structure, the model is able to project the optimal internal price between the firm’s subsidiaries or divisions located in different countries as they ship the components or semi-finished products and the finished product across the supply chain to the external market destination. Therefore, the transfer price is an instrument that the company utilizes to manage and shift the global incomes of the firm.

Transfer price is one of the most controversial topics for multinational companies, but only few authors consider transfer pricing as an explicit decision in their model. In fact, most researchers in global logistics have considered transfer price a typical accounting problem rather than an important decision opportunity that significantly affects the design and management of a global supply chain. Thus, in most existing global supply chain management models that attempt to determine the optimal flows of products among facilities, the transfer prices are considered as fixed parameters. However, transfer pricing is one of the most important issues in profit maximization of multinational companies, and management departments of real global firms can determine the transfer price with some flexibility within given limits.

Undoubtedly, the transfer price problem is more than an accounting problem as they can influence significantly taxable income, duties and, therefore, the after tax profit of multinational companies. Transfer price policies have significant effects on performance
evaluation and motivation of subsidiary managers because the choice of internal prices not only affects the overall profits of a global company, but it also affects the profits of each internal division. Actually, managers find transfer pricing to be an important factor for maximizing operating performance and considering transfer pricing without regarding costs and profits of the internal divisions would be an unfair measure of contribution to the company. For instance, assuring some profit to a manufacturing division is particularly important if the company wants the manager to improve the efficiency of the production process by making some investments. Moreover, the method used for setting transfer prices directly influences the decisions delegated to division managers because they are typically evaluated and compensated based on the reported income of their divisions. That’s why making transfer price decisions for multinational companies is an important, complex, flexible and complicated task because it affects the global firm’s profits but also affects all the internal divisions involved. With this point of view it is proposed a global supply chain management model for the problem of a multinational corporation that attempts to maximize its global after tax profits by determining the flow of goods and the transfer prices, taking into consideration the division or subsidiaries costs and profits.

If we consider transfer pricing as a strategy of determining the transfer price, small changes in transfer price may lead to significant differences in the after tax profit of a company because the impact of transfer price policies on taxable income, duties and management performance is significant. Indeed companies can use transfer price to show reduced profits and thereby pay less taxes, especially when activities are distributed in different tax jurisdictions with different tax rates. Thus, as transfer pricing is used as a strategy to manipulate profit distribution, many countries have tax regulations to limit the ability of firms to use transfer pricing as a trick of tax mitigation. So the arbitrary manipulation of transfer prices is currently under careful observation by tax authorities and is strictly penalized, but companies have some range of values for their transfer prices. Most countries have adopted transfer pricing methods based on the arm’s length principle defined in the Organization for Economic Cooperation and Development (OECD) which defines a range of an acceptable transfer price rather than a single correct transfer price. Based on this principle, the transfer price should be the best estimate of the price if the two divisions involved are independent entities rather than parts of the same firm. It means that companies should use a transfer price based on average market value. In this case, the determination of the transfer price is not very complicated when the component or intermediate product has its own market outside the firm but, however, it is difficult to determine the market value for components or semi-finished products specific to the firm and not sold outside the company. That’s why some authorities allow the use of any other unspecified method if its use can be justified. Therefore, transfer price is typically determined by using the actual cost of producing the product as a base and then adding a markup or profit margin to this base to derive the internal selling price of the company.

Purpose of the paper: In this paper we develop a profit maximization optimization model that is specific to the design of global supply chains while integrating transfer pricing. The aim of this model is to design transfer pricing practices that minimize taxes and can be justified to authorities. We consider the problem of multinational companies
that attempts to maximize its global after tax profits by determining the flow of goods and
the transfer prices, taking advantage of differential tax structures among countries but that
can be justified to tax authorities. The model must determine the amount of raw material
or components to be shipped from each external supplier to each production center and to
each production center to each facility, as well as the transfer prices of the components or
semi-finished products. For the arcs between facilities and destination centers, the model
must determine the amount of finished product to be delivered as well as the transfer
prices of the finished product. The model captures the characteristics of the supply
chain design problem such as existing capacities, flow of materials, intermediate products
and echelons in the supply chain. In addition, we integrate transfer pricing in the model
because of the correlation existing between transfer pricing and supply chain management
and because of the tax advantages offered by some countries that motivate global supply
chain projects. Therefore, there are two distinct but related decisions in the model: the
product flow and the transfer prices. The product flow pertains to the production and
shipment of intermediate and finished products between producing countries in order to
satisfy the demand of the external markets. The transfer prices allocate the revenues to
the different sites in order to meet all their costs and provide them operating profits.

We consider a transfer pricing method based on costs and market price. We impose ac-
ceptable lower and upper bounds on the transfer prices of each semi-finished and finished
product. This assumes that, on one hand, for the finished product a number of similar
products are available in the free market with known prices. So the lower and upper
bounds for the finished product can be determined comparing products of the external
market. On the other hand, it is very difficult to find comparable products for compo-
nents or semi-finished products that are shipped inside the company and not sold to the
external markets. In this case, production and transportation costs are considered for the
determination of the lower and upper bounds.

To evaluate the efficiency of the model, we conduct a computational study and derive
a series of insights. This study evaluates the performance of our solution procedure and
investigates through sensitivity analysis the impact of factors such as variation of taxation
rates, selling prices or production costs, a reduction in the global production capacity and
demand variability on the external market. This paper makes a contribution by firstly,
developing an optimization model of a global supply chain network that a firm can utilize
to optimally integrate manufacturing and distribution location decisions. We secondly
integrate the transfer pricing in the model by using acceptable lower and upper bounds
that can be determined by market prices and production and transportation costs. And
finally, using the model we derive a series of insights that would be difficult to obtain
without the support of models like the one developed here. The model can be implanted
in a decision support system to help a firm with global operations design generating
increased profits and reduced tax liabilities in its supply chain.

The reminder of this paper is organized as follows: Section 2 is the review of the
relevant literature to the model proposed. Section 3 describes the framework of the
studied problem. Section 4 describes the mathematical formulation of the model. Section
5 presents computational experiments and potential insights that the model can provide.
Finally, Section 6 provides the conclusions.
Chapter 2

Literature review

In this section, we review selected literature on strategic planning models that integrate traditional supply chain design variables such as manufacturing, distribution and transportation costs and capacities with transfer prices and local taxes.

There is an abundant literature on supply chain design optimization models. The review of this literature aims to understand how existing models take into consideration the characteristics of the supply chain design problem addressed in this paper. With this scope in mind, we review the published works according to the following dimensions:

- **Nature of the objective function**: Supply chain optimization models either maximize a profit function or minimize a cost function. Even though most models are orientated to the minimization of the costs, profit maximization models fits better to the problem presented because with profit maximization models taxation issues are considered in the global context.

- **Number of echelons in the supply chain**: The definition of the different existing echelons in a global supply chain network is very important for the understanding of the missions of facilities and the flows of products. Thus, echelons like external suppliers, manufacturing plants, destination centers and external markets should be understood perfectly for the development of the model.

- **Intermediate products**: The intermediate or semi-finished products play a key role in the supply chain design problem because the global supply chain projects are often concerned with intermediate products. Indeed, it is common that a firm keeps the final product close to the customer site while locating the manufacturing of intermediate products in different countries. Also the integration of transfer pricing raises the role of intermediate products as this gives more possibilities of increasing the global after tax profits by using the transfer price of intermediate products.

- **External suppliers**: The global supply chain projects may, in some cases, be motivated by the access to some strategic external suppliers.

- **Transfer pricing**: The interest of including transfer pricing has been highlighted in the Introduction section. On one hand, most published works consider the transfer
price as a parameter or a fixed value but it is known that little variations in the transfer price can affect significantly in the profits of the global company. On the other hand, supply chain projects with integration of transfer pricing leads with difficulties like the justification of the transfer price or the good coordination between the different subsidiaries of the same company.

- **Taxation**: The integration of transfer pricing affects directly to the after tax profits of the company. Therefore it is important to take into consideration the taxation policies of the different countries.

The results of our literature review are summarized in Table 1 where the focus is made on most recent papers and those that are relevant to our problem.

**Table 2.1: Classification of literature review**

<table>
<thead>
<tr>
<th>Article</th>
<th>Max. profit in Obj. Fct</th>
<th>Echelons in the SC</th>
<th>Intermediate products</th>
<th>External suppliers</th>
<th>Transfer pricing</th>
<th>Taxation rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamami and Frein (2014)</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Matta and Miller (2014)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Plesner et al. (2013)</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
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<td>x</td>
</tr>
<tr>
<td>Taylor and Lanis (2013)</td>
<td></td>
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<td></td>
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<tr>
<td>Pendse et al. (2012)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Matsui et al. (2011)</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Perron and Hansen (2009)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Lakhal et al. (2005)</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lakhal and H’ Mida (2003)</td>
<td></td>
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<td>x</td>
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<tr>
<td>Vidal and Goetschalckx (2001)</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>This model</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
One can first observe that, although profit maximization is increasingly considered in recent works, most models still minimize a cost function. The fact that only few optimization models focus on profit maximization is rather surprising since most business activities are profit-oriented.

Most existing works consider a simplified structure of the supply chain network. Indeed the missions of the facilities and warehouses and restrictions on the product’s flows between different sites are always defined. Recent papers have also given adequate attention to the integration of external suppliers.

Otherwise, few works study semi-finished products that are shipped between the manufacturing plants. The supply chain design models generally focus on finished products and purchased components. Indeed, the supply chain design models that simultaneously handle purchased products, semi-finished products and finished products are still undeveloped.

The most relevant published papers to the problem are those that deal with supply chain design while including global factors such as transfer pricing or taxation rates, but most published works do not take into consideration this factors. Furthermore, authors that consider transfer pricing in their works don’t contemplate it as an explicit decision variable of their model. In fact, when it is considered, the transfer price is usually introduced as an input parameter and not a decision variable. Moreover, the few works that consider the transfer price as a decision variable don’t explain the determination of the lower and upper bounds of the transfer price. But recent studies show the possibility of setting transfer prices based on available market prices for existing intermediate and finished products. The problem is that semi-finished products are usually exclusive of the company and they are not sold outside. In these cases when the market price is not available, the production cost can be used in order to determine the transfer price. However, papers in the existing operations management literature that use production cost for the determination of the transfer price are hard to find.

The mixed integer optimization model of Hammami and Frein (2014) is a complex and large global profit maximization model but considers an arbitrary number of echelons and capacity relocation decisions, which is not the interest of this paper. The problem formulated by Matta and Miller (2014) is a strategic manufacturing and distribution network model that integrates transfer pricing decisions. It can be utilized by companies for their supply chain network design. However, it is a mixed integer nonlinear programming model, which makes it difficult to solve and it needs a heuristic procedure in order to be solved. Perron and Hansen (2009) and Vidal and Goetschalckx (2001) propose global supply chain management models that attempt to maximize the after tax profits of a multinational company integrating the transfer prices as a decision variable. The models define clearly the different levels in a global supply chain (suppliers, manufacturing plants, distribution centers and customers), but they are also nonlinear programs. The paper from Lakhal et al. (2005) proposes a mathematical model for the calculation of transfer prices in network-manufacturing ventures, but it considers company network within the same economic region, with similar tax rates and structures. Lakhal an H’Mida (2003) developed a method to find a transfer price for each product based on a market-driven transfer price model. However, it assumes that a number of similar products are available
in the free market with known prices, which rarely happens with semi-finished products.
Chapter 3

Problem description

We consider a global supply chain network of a company with different manufacturing and distribution sites for semi-finished and finished products. The company produces a single finished product and we assume a unit of output at each facility requires a unit of each input. In other terms, raw material is purchased by the firm from an external supplier (input) and one unit of component (output) is produced, then one unit of finished product is made with one unit of each component needed for the production. For instance, in the paper industry the manufacturing process can be decomposed into the following three activities: purchase of paper rolls from external suppliers, paperboard manufacturing and paperboard box manufacturing. In this example the intermediate product could be substituted or sold to external markets, but for simplicity, in this model we consider semi-finished products to be proprietary goods for which there are no close substitutes on external markets and they are not sold to outside parties.

The manufacturing and distribution network of the company is formed by three echelons: components production centers where the semi-finished products are made, facilities for the manufacturing of the finished product and distributing centers where the finished product is sold to the external markets. The set of all components production centers is denoted by $I$ and the sets of the centers producing each component are denoted by $I_1$, $I_2$, $\cdots$, $I_n$ respectively ($I = I_1 \cup I_2 \cup \cdots \cup I_n$). Only one component is produced in each center, if in one country more than one component is produced the number of centers will be equal to the number of components. Each center need to buy from an external supplier with a purchase cost, they also have fabrication cost and their capacity is limited. The transportation cost of the components shipped from each center to each facility in order to produce the final product is assumed to be charged to the components centers.

The next step is the production of the final product with the components received from the components production centers. The set of all facilities is denoted by $J$. Each component or semi-finished product is shipped from one component producer center to one of the facilities located in different countries where the final product is manufactured. This process has an operational cost and when the product is finished it is shipped to a distribution center. The transportation cost of the final products shipped from each facility to each distribution center is assumed to be charged to the facilities.

The set of distribution centers is denoted by $K$. They are located in different market
areas with different demands where they sell the final product with an internal selling price that includes the market price and the operational costs. Therefore, distribution centers receive finished goods from plants and then subsequently ship the product to the firm’s external customers, this flow from the distribution center to the external customer represents the actual sale by the firm to its paying customers.

The potential manufacturing plants \((C_i \text{ and } F_j)\) and distribution centers \((W_k)\) at selected country are subsidiaries or affiliates of the firm. Further, the different manufacturing and warehouse locations are physically located overseas in countries with different tax rates on profits. Plants ship intermediate and finished products around the world, but these flows also include domestic shipments where a plant in a country delivers semifinished or finished goods to a facility or warehouse in the same country. For instance, a component can be produced in Japan, then shipped to the Japanese facility for the manufacturing process and when the final product is ready it is shipped to a distribution center located also in Japan.

The price or value of a unit of product increases as it moves through the network. A plant ships a product to another country at an agreed upon price (transfer price). This price, at the minimum, includes the cost of production, as well as a markup on the production cost of the producing plant. It also includes additional cost components such as transportation costs. Finally, the transfer price that a plant charges the local affiliate to which it delivers the product also includes a markup or profit margin. Finally, the firm recognizes and evaluates the local taxes paid on the profits recorded by the plant selling an intermediate or final product to another plant or warehouse, and on the profits generated by the distribution centers selling to the external customers.

Figure 1 is an example of the network model explained before. It describes the flow inside a company of the intermediate components and the finished product between the same or different countries. The first echelon is formed by four component production centers \((C_i)\), each one of them buys from an external supplier \((S_i)\) and produces one of the components needed for the final product. In the example there are two components to be produced and they are defined in red in the diagram, \(C_1\) and \(C_2\) produce component 1 and \(C_3\) and \(C_4\) produce component 2. In the second echelon there are two facilities \((F_j)\) for manufacturing all the demand of final product. They receive all the components from \(C_i\). Therefore, each facility must receive components from at least one between \(C_1\) and \(C_2\) and at least one between \(C_3\) and \(C_4\). When the finished product is made it is shipped from the facilities to each distribution center \((W_k)\). There are three \(W_k\) and they are located in three different external markets \((M_k)\) with different demands where the product is sold on the local price.

The subsidiaries of the firm are located in five different countries. Each group of sites delimited by discontinuous lines represents one country, therefore all the sites located in the same country will have the same tax rate but every country will impose different tax rates. Country 1 is the country with the highest tax rate (35%) and country 3 is the one with the lowest tax rate (10%), the other countries have intermediate taxes that are between 30 and 20%.

The main decisions that are undertaken by the model are the following:

- Production planning: The model selects the amount of semi-finished and finished
Figure 3.1: Network representation of the model
product that should be produced in each production center or facility in order to satisfy the demand and maximize the global profits of the company.

- Transportation planning: The proposed model determines the shipment of semi-finished and finished products along the manufacturing and distribution network for the adequate production and delivery of the products.

- Transfer pricing: The model determines the transfer prices for all semi-finished and finished products that are shipped from one site to another site of the company.
Chapter 4

The model

We formulate the model as a single period mixed integer optimization model. The fabrication cost to produce components and finished product is known as well as the transportation cost between locations (the firm has evaluated these costs as a part of the strategic planning process). We also assume external suppliers with unlimited capacity, plants with limited capacity and distribution centers with enough capacity for satisfying the demand of the external market. We now formulate the problem using the following notation.

i = index on the number of component production centers, i = 1, 2, 3, 4.

j = index on the number of facilities, j = 1, 2.

k = index on the number of destination centers, k = 1, 2, 3.

4.1 Decision variables

\( bp_{Ci} \) (or \( bl_{Ci} \)) : before tax profit (or loss) of production center i,

\( bp_{Fj} \) (or \( bl_{Fj} \)) : before tax profit (or loss) of facility j,

\( bp_{Wk} \) (or \( bl_{Wk} \)) : before tax profit (or loss) of distribution center k,

\( g_i \) : quantity of component or semi-finished product produced by production center i,

\( h_j \) : quantity of finished product produced in facility j,

\( x_{ij} \) : quantity of component or semi-finished product produced by production center i and shipped to facility j,

\( y_{jk} \) : quantity of finished product produced in facility j and shipped to destination center k,

\( tp_{ij} \) : unit transfer price paid by facility j to component production center i for the purchase of one unit of component or semi-finished product,

\( t_{jk} \) : unit transfer price paid by destination center k to facility j for the purchase of one unit of finished product.
4.2 Parameters

\( QC_i \): Production capacities of semi-finished product by production center \( i \).

\( QF_j \): Production capacities of finished product by facility \( j \).

\( D_k \): Demand of finished product in external market where the destination center \( k \) is located.

\( pC_i \): purchase price for the production of one unit of component in production center \( i \). It includes the transportation cost imputed to site \( i \).

\( c_i \): unit fabrication cost of components in production center \( i \).

\( a_{ij} \): unit transportation cost of component from production center \( i \) to facility \( j \). This cost is assumed to be charged to the origin site.

\( e_j \): fabrication cost of one unit of finished product in facility \( j \).

\( b_{jk} \): unit transportation cost of finished product from facility \( j \) to destination center \( k \). This cost is assumed to be charged to the origin site.

\( s_k \): unit selling price of finished product by destination center \( k \) to the external market. This price includes the market price and the operational costs of the site \( k \).

\( n_i \): income tax in the country of component production center \( i \). We assume that the tax rate is null if the company makes a loss.

\( m_j \): income tax in the country of facility \( j \). We assume that the tax rate is null if the company makes a loss.

\( r_k \): income tax in the country of destination center \( k \). We assume that the tax rate is null if the company makes a loss.

\( lbC_{ij} \): lower bound on the transfer price of component shipped from site \( i \) to facility \( j \).

\( ubC_{ij} \): upper bound on the transfer price of component shipped from site \( i \) to facility \( j \).

\( lbF_{jk} \): lower bound on the transfer price of finished product shipped from facility \( j \) to destination center \( k \).

\( ubF_{jk} \): upper bound on the transfer price of finished product shipped from facility \( j \) to destination center \( k \).
4.3 Objective Function

The objective is to maximize the global after tax profit of the company. In order to achieve this, first it is necessary to calculate the before tax profit of each site. It represents the difference between the revenues and the expenses of each component production center i, each facility j and each destination center k. Revenues in destination center k are generated from selling products to external markets and in sites i and j they are generated from selling products or components inside the company (transfer price). Otherwise, expenses include all costs imputed to site i, j or k.

The expression of the before tax profit depends on whether the site is a component production center i or a facility j or a destination center k.

For a component production center i the value of the before tax profit is given by expression (4.1). Indeed, the revenues are generated from selling semi-finished products to facilities \( \sum_{j=1}^{2} t_{pij} x_{ij} \). The costs regroup the purchasing cost from the external suppliers \( pC_{i}g_{i} \), the fabrication cost of the components \( c_{i}g_{i} \) and the transportation cost \( \sum_{j=1}^{2} a_{ij} x_{ij} \).

\[
bpC_i - blC_i = \sum_{j=1}^{2} (tp_{ij} - a_{ij}) x_{ij} - (pC_{i} + c_{i}) g_{i}
\]  
(4.1)

For a facility j the value of the before tax profit is given by expression (4.2). In this case, the revenues are generated from selling finished products to the destination centers \( \sum_{k=1}^{3} t_{jk} y_{jk} \). The costs regroup the internal purchasing cost of components from production centers \( \sum_{i=1}^{4} tp_{ij} x_{ij} \), the fabrication cost of the finished product \( e_{j}h_{j} \) and the transportation cost \( \sum_{k=1}^{3} b_{jk} y_{jk} \).

\[
bpF_j - blF_j = \sum_{k=1}^{3} (t_{jk} - b_{jk}) y_{jk} - e_{j}h_{j} - \sum_{i=1}^{4} tp_{ij} x_{ij}
\]  
(4.2)

Finally, for a destination center k the value of the before tax profit is given by expression (4.3). The revenues are generated from selling finished products to the external market \( s_{k} \sum_{k=1}^{3} y_{jk} \). The operational costs are included in the internal selling price. The reminder of the costs comes from the purchase of finished product manufactured in the facilities \( \sum_{j=1}^{2} t_{jk} y_{jk} \).

\[
bpW_k - blW_k = s_{k} \sum_{j=1}^{2} y_{jk} - \sum_{j=1}^{2} t_{jk} y_{jk}
\]  
(4.3)
The after tax profit in a component production center $i$, facility $j$ or destination center $k$ is determined by subtracting the percentage of the profit taken by the tax imposed in each country. When the site has a loss, taxes are not considered for the final result of this site. Thus, the global after tax profit of the company is given by expression (4.4).

$$ \sum_{i=1}^{4} (1 - n_i)bpC_i - blC_i + \sum_{j=1}^{2} (1 - m_j)bpF_j - blF_j + \sum_{k=1}^{3} (1 - r_k)bpW_k - blW_k $$ (4.4)

### 4.4 Constraints

#### 4.4.1 Capacity and flow constraints

Each production center or facility has a capacity of production and with constraints (4.5) and (4.6) these limitations are guaranteed. $QC_i$ is the capacity of production of center $i$ and $QF_j$ is the capacity of production of facility $j$.

$$ g_i \leq QC_i, \quad i = 1, 2, 3, 4 $$ (4.5)

$$ h_j \leq QF_j, \quad j = 1, 2 $$ (4.6)

Now, we turn to modeling the production conditions. If an output finished product is located in facility $j$ then the quantity of product pushed to a destination center $k$ must be equal to the quantity of product generated in facility $j$. The same happens with a semi-finished product produced in center $I$ and shipped to facility $j$, and this is guaranteed by constraints (4.7) and (4.8).

$$ \sum_{j=1}^{2} x_{ij} = g_i, \quad i = 1, 2, 3, 4 $$ (4.7)

$$ \sum_{k=1}^{3} y_{jk} = h_j, \quad j = 1, 2 $$ (4.8)

The requirements of facility $j$ regarding input component are calculated based on the quantities of output product generated by $j$. Note that facility $j$ may have different amount of output product and for the production of one unit of finished product each component is necessary. Thus, the requirements of facility $j$ regarding input products (components or semi-finished products) must be acquired from the production centers $i$ as guaranteed by constraints (4.9) and (4.10).

$$ x_{1j} + x_{2j} = \sum_{k=1}^{3} y_{jk}, \quad j = 1, 2 $$ (4.9)

$$ x_{3j} + x_{4j} = \sum_{k=1}^{3} y_{jk}, \quad j = 1, 2 $$ (4.10)
The demand of the external market must be satisfied as guaranteed by constraints (4.11) where $D_k$ is the demand of finished product by external market $k$.

$$
\sum_{j=1}^{2} y_{jk} = D_k, \quad k = 1, 2, 3
$$ (4.11)

### 4.4.2 Determination of transfer prices

The values of transfer price are included in the objective function to obtain an optimal solution for the after tax profit. There are two different types of transfer price, the one paid for the internal shipment of components or semi-finished products ($t_{p_{ij}}$) and the transfer price paid for the internal shipment of finished product ($t_{j_k}$).

We first assume that comparable products may be found in the external market for the finished product. Therefore, we can determine lower and upper bounds on the transfer price of finished product shipped from facility $j$ to destination center $k$, which defines an interval of acceptable values of the transfer price. Secondly, we consider production and transportation costs in the decision of transfer price for semi-finished products that do not have comparable products in the external market. Therefore, we can determine lower and upper bounds on the transfer price of components or semi-finished products shipped from production center $i$ to facility $j$. The model is free to choose a transfer price value from this range of acceptable values as guaranteed by constraints (4.12) and (4.13). This approach allows us to capture transfer price decisions in Supply Chain models without increasing the modeling complexity.

$$
lbC_{ij} \leq t_{p_{ij}} \leq ubC_{ij}, \quad i = 1, 2, 3, 4; j = 1, 2
$$ (4.12)

$$
lbF_{jk} \leq t_{jk} \leq ubF_{jk}, \quad j = 1, 2; k = 1, 2, 3
$$ (4.13)

The determination of the bounds is very important and delicate because the transfer price may be rejected by fiscal authorities if managers are not able to define reliable lower and upper bounds. We denote by $lbC_{ij}$ and $ubC_{ij}$ the lower and upper bounds respectively on the transfer price of one unit of component or semi-finished product sold by production center $i$ to facility $j$. Thus, the following equations define the bounds of the model.

$$
lbC_{ij} = pC_i + c_i + a_{ij}
$$ (4.14)

$$
ubC_{ij} = lbC_{ij} + e_j + b_{jk}
$$ (4.15)

We denote by $lbF_{jk}$ and $ubF_{jk}$ the lower and upper bounds respectively on the transfer price of one unit of finished product sold by facility $j$ to destination center $k$. Equations (4.16) and (4.17) define the bounds of the model.

$$
lbF_{jk} = e_j + b_{jk} + Min_1 \{lbC_{ij}\} + Min_2\{lbC_{ij}\}
$$ (4.16)

$$
ubF_{jk} = s_k
$$ (4.17)
4.5 Linearization

The objective function (4.4) is not linear due to the multiplication of integer variables $x_{ij}$ (respectively, $y_{jk}$) by non-negative variables $tp_{ij}$ (respectively, $t_{jk}$). Therefore, we need to linearize the objective function in order to simplify the solvability of the model.

We let $TP_{ij} = tp_{ij}x_{ij}$ for all production centers $i$ and facilities $j$ and we also define $T_{jk} = t_{jk}y_{jk}$ for all facilities $j$ and destination centers $k$. With this change, instead of calculating the unit transfer price, we calculate the total transfer price paid between facilities. Thus, it can be proven that non-linear objective function (4.4) is equivalent to equation (4.18).

$$\sum_{i=1}^{4} (1 - n_i) \cdot \left[ \sum_{j=1}^{2} (TP_{ij} - a_{ij}x_{ij}) - (pC_i + c_i)g_i \right]$$ (4.18)

Finally, the set of constraints for the transfer price change into constraints (4.19) and (4.20).

$$lb_{C_{ij}}x_{ij} \leq TP_{ij} \leq ub_{C_{ij}}x_{ij}$$ (4.19)
$$lb_{F_{jk}}y_{jk} \leq T_{jk} \leq ub_{F_{jk}}y_{jk}$$ (4.20)

With this reformulation, the quantity of semi-finished or finished products shipped is included in the constraints of the transfer prices and unacceptable situations are avoided. Indeed, the transfer price of a given product is paid by production center $i$ to facility $j$ (or respectively paid by facility $j$ to destination center $k$) only if $i$ provides $j$ with the component (or respectively $j$ provides $k$ with the finished product). In other words, if $x_{ij} = 0$ then we will have $TP_{ij} = 0$, and if $y_{jk} = 0$ then we will have $T_{jk} = 0$.
Chapter 5

Numerical examination

The numerical examination is conducted on a hypothetical case study and is guided by the following goals. Firstly, focuses the goals of introducing transfer price decisions in our supply chain design model. Secondly, analyze the impacts of international factors (taxation policies). Finally evaluate the effects caused by variations in parameters like production or transportation costs, selling prices, capacities and demand. Based on these experiments, we derive insights that can be helpful for companies and governments. We use the commercial optimization software Gurobi (connected with Python) to solve the model.

We consider one finished product that is delivered to three destination centers located in three different countries. The finished product is manufactured in two different facilities and one of them is located in a low-cost site with low taxes. We consider two components or semi-finished products to be delivered to the facilities for the manufacturing of the finished product. The components are manufactured in four production centers, two of them produce one kind of component and the other two produce the other kind. The production centers are located in three different countries, being two of them in a low-cost site with low taxes. Thus, each component can be manufactured in in the low-cost site.

According to the methodology adopted in the development of the model, the production process can be decomposed into three different and independent activities: the production of components or semi-finished products, the manufacturing of the finished product in facilities and the selling product to external markets by destination centers. It is a single-period model and the length of the period is one year. External supplier’s capacities are assumed to be large enough.

For the base scenario, the annual demand is 310,000 units and the capacity of all production centers and all facilities is 200,000 units. The selling price is respectively 80, 83 and 88 Euro for the three external markets considered. It includes the operational cost and the transportation cost towards costumer. The income tax rate in the high-cost country is 35% which is a reasonable value while only 10% of taxes are paid in the low-cost country. The values of the other parameters and costs are showed in the appendix with the formulation of the model in the python language.
5.1 Contribution of the transfer price

In order to analyze the impact of the transfer price as a decision variable for a global supply chain network, the model is studied in three cases:

- Case 1: transfer prices are considered as decision variables and they are determined by adding lower and upper bounds on the transfer price. The values of the bounds are fixed considering selling prices and costs.

- Case 2: transfer prices are considered as fixed parameters of the model. The values of the transfer price are fixed as the mean of the bounds obtained in the first case.

- Case 3: transfer prices are not included in the model. In both second and third case, the model is modified and the different transfer price constraints are removed.

Comparing the global optimal after tax profit in all cases, the large average profit is obtained with the first case. With the inclusion of transfer prices as decision variables the model manipulates the transfer prices to pay less taxes and increases the total profits. Indeed, the model has freedom to manipulate transfer prices between the bounds imposed and is able to find the values of transfer prices that maximize the total profits. On the other hand, the profit obtained in the third case is smaller than the profit in the first case as, without the inclusion of transfer pricing in the supply chain network, the model cannot take advantages of low-tax jurisdictions. Finally, the smallest profit is obtained with the second case (introduction of transfer prices as fixed parameters). Although in this case transfer prices are also used as a tool to move profits to countries with low taxes, the optimal transfer price for this strategy cannot be found if it is already fixed. The inflexibility of transfer price in this case makes this model even worse than the case without transfer price. This fact emphasizes the difficulty of choosing an optimal transfer price without a model and, therefore, the importance of transfer price as a decision variable. Indeed, in average, the profit obtained in case 2 is 21% smaller than the profit of case 1 and the profit obtained in case 3 is 18% smaller than the profit of case 1.

After analyzing the results obtained in the three cases, two more cases have been studied in order to evaluate the importance of transfer price as a decision variable:

- Case 2.1: transfer prices are considered as fixed parameters of the model. The values of the transfer price are fixed as the lower bounds obtained in the first case.

- Case 2.2: transfer prices are considered as fixed parameters of the model. The values of the transfer price are fixed as the upper bounds obtained in the first case.

Comparing the global optimal after tax profit of these two last cases with the cases above, the after tax profits are still the smallest even if the values of the fixed transfer prices have changed. This shows again the importance of transfer prices as decision variables in the model if they are used as a tool for the shipment of profits and maximization of the global after tax profits. Indeed, when transfer prices are fixed and chosen in advance they are rarely optimal and, as a little variation in the transfer price can induce a large variation in global profits, when transfer prices are not selected carefully they can be counterproductive for the company.
Table 5.1: Comparison between models

<table>
<thead>
<tr>
<th>Case</th>
<th>Transfer price</th>
<th>After tax profit</th>
<th>Decrease of profits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>Variable</td>
<td>6,749,050.00 E</td>
<td>-</td>
</tr>
<tr>
<td>Case 2</td>
<td>Fixed (mean)</td>
<td>5,340,500.00 E</td>
<td>21%</td>
</tr>
<tr>
<td>Case 3</td>
<td>Not considered</td>
<td>5,560,040.00 E</td>
<td>18%</td>
</tr>
<tr>
<td>Case 2.1</td>
<td>Fixed (lower bound)</td>
<td>5,525,000.00 E</td>
<td>18%</td>
</tr>
<tr>
<td>Case 2.2</td>
<td>Fixed (upper bound)</td>
<td>5,245,000.00 E</td>
<td>22%</td>
</tr>
</tbody>
</table>

Figure 5.1: Impact of transfer price
5.2 Impacts of tax rate

In order to evaluate the impacts of the tax rate in the profits of the company, the taxation policy in the low-cost country is studied. This tax is progressively increased from an initial value of 0% until 50%. The expectation was to find that the larger the tax rate the smaller the after tax profit of the company becomes. However, unlike what was expected, the variation of tax rate not always affect the global profits of the company. The experiment is made with the three cases described before (transfer price variable, transfer price fixed and without transfer price), and only the case with transfer price as a fixed parameter.

Comparing the global optimal after tax profit in all cases, it is easy to see how it vary as a function of the tax rate in the low-cost country.

- For the case of transfer price as a decision variable, the after tax profit decrease when the tax rate increases from 0% to 20%. This can be explained by the fact that between these ranges the country keeps being the low-cost country but each time with less difference with the other countries. Thus, the use of the transfer price as a tool to shift profits to low-cost countries is less effective. If the tax rate reaches 20% the country is not anymore the low-country and the model can manipulate the values of transfer price to shift profits from this country to the origin site in order to maximize the global after tax profit. This explains why the after tax profit remains unchanged.

- For the case of transfer price as a fixed parameter, the after tax profit always decrease when the tax rate increases. This is explained by the fact that the model cannot manipulate the values of transfer price to shift profits from this country to the origin or destination site in order to maximize the global after tax profit.

- For the case without transfer price, the after tax profit remains constant when the tax rate increases. In this situation the low-cost country is not considered a country with an external market to sell finished products, it is only considered a country with low production costs and then, ideal for the location of facilities or production centers. Therefore, a change of the tax rate in this country does not affect the global after tax profit because the site in this country will never have before tax profits.
Three situations are considered for the study of the impacts of the capacities in facilities and production centers. In order to see how a reduction or increase of the capacity affects the total profits and the flow of the products through the network, the model is studied in the base scenario, with a significantly increase of capacities (enough to produce all the demand of finished product in only one facility) and with a significantly decrease of capacities (enough to produce all the demand of finished product with all facilities operating at full capacity).

If capacities are reduced considerably each facility and production center has to work at full capacity in order to satisfy the demand, but if capacities are increased the model has more freedom to choose the best flow of semi-finished and finished products. Therefore, greater capacities allow the model to find a better optimal solution for the global profits, but it can cause unexpected new costs. Because in this situation some production centers or facilities do not produce any product and this may origin costs of facility closing or fixed costs that are not considered in this model.
5.4 Impacts of costs and prices

In order to evaluate the impact of the production costs, this cost is progressively decreased from its initial value to 0. It is found out that the lower are the production costs the more important are the transportation costs. Indeed, when production costs are decreased the production in high-cost countries increases because they are located close to the external markets and transportation costs are lower.

The same happens with a decreasing of the transportation costs. It means that when one cost is irrelevant the other takes more importance for the design of production and flow of the products. In this case, however, production in high-cost countries increase with a rise of transportation cost. This can be explained by the fact that low-cost countries are located far from the external market and even if taxes and production costs are lower when transportation costs are too high the other factors become irrelevant.

It also can be seen that in all cases (transfer price as a decision variable, transfer price as a fixed parameter and without transfer price) the behavior of the sites in the model is the same.

On the other hand, if both costs are decreased at the same time the decisions of the model are based exclusively in the tax rates. Thus, when costs of production and transportation are irrelevant, facilities and production centers located in low-tax countries work at full capacity and sites located in high-tax countries work at the minimum capacity possible.

Finally, the selling price is also studied by increasing the selling price of a different
external market each time. This procedure shows that the selling price affects the global supply chain design. When an external market has a significantly higher selling price the model change the design of the global network (manufacturing and flow of semi-finished and finished products) in order to give preference to this external market.
Figure 5.5: Increase of transportation cost
Chapter 6

Conclusion

This paper presents a global supply chain optimization model that includes explicitly transfer prices as a decision variable. Therefore, the proposed model can help managers to take global logistics decisions like production activities or distribution of semi-finished and finished products and it can also help managers to take decisions of the bests transfer prices for the maximization of the total after tax profits. The model determines the transfer price of semi-finished and finished products transferred along the global supply chain by imposing acceptable bounds on the values of transfer prices. These bounds are justified by external market prices in the case of the finished product and, for the case of semi-finished products, purchase, production and transportation costs have been considered. The model has a single-period planning horizon and considers a supply chain with a defined number of echelons that include finished, semi-finished and purchased products.

The model is non-linear and a linearization approach is proposed. The model was optimally solved by Gurobi, first with a base scenario and after choosing interesting alternatives. We compared three versions of the model: the defined model with transfer prices as decision variables determined by imposing bounds, a modification of the model with transfer prices as fixed parameters and a modification of the model with transfer prices not included.

This work may be extended in different directions. Further research should consider exchange rates as they could have a significant impact in the global manufacturing network. It is also interesting to adapt the model for the inclusion of fixed costs and a multi-period planning horizon. Finally, another interesting direction of research would be the study of different transfer pricing methods.
References


Acknowledgements

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I would like to also thank all my Japanese and International lab mates. They help me in many ways and make my life in Japan colourful.

Last but not least I would like to dedicate this thesis to my family in Spain who always help me so much and consistently support me.
Appendix: Programming in Python/Gurobi

from gurobipy import *

# Parameters:
D = [120, 100, 90]
QF = [200, 200]
QC = [200, 200, 200, 200]
a = [[3, 10],[7, 9],[7, 9],[11, 4]]
b = [[4, 15, 16],[21, 20, 18]]
s = [80, 83, 88]
c = [8, 7, 8, 5]
PC = [5, 3, 3, 2]
e = [14, 12]
n = [0.65, 0.8, 0.8, 0.9]
m = [0.65, 0.9]
r = [0.65, 0.7, 0.75]
lbC = [[16, 23],[17, 19],[18, 20],[18, 11]]
ubC = [[34, 53],[35, 49],[36, 50],[36, 41]]
lbF = [[52, 63, 64],[63, 62, 60]]
ubF = [[80, 83, 88],[80, 83, 88]]

# Range of component makers, facilities and warehouses:
C = range(len(n))
F = range(len(m))
W = range(len(r))

# Model:
v = Model("GSC")

# Decision Variables:

x = []
for i in C:
x.append([])
for j in F:
x[i].append(v.addVar(vtype = GRB.INTEGER, name = "x%d.%d" % (i, j)))
y = []
for j in F:
y.append([])
for k in W:
y[j].append(v.addVar(vtype = GRB.INTEGER, name = "y%d.%d" % (j, k)))
h = []
for j in F:
h.append(v.addVar(vtype = GRB.INTEGER, name = "h%d" % j))
g = []
for i in C:
g.append(v.addVar(vtype = GRB.INTEGER, name = "g%d" % i))
tp = []
for i in C:
tp.append([])
for j in F:
    tp[i].append(v.addVar(name = "tp%d.%d" % (i, j)))

t = []
for j in F:
t.append([])
for k in W:
    t[j].append(v.addVar(name = "t%d.%d" % (j, k)))

bpC = []
for i in C:
    bpC.append(v.addVar(name = "bpC%d" % i))

blC = []
for i in C:
    blC.append(v.addVar(name = "blC%d" % i))

bpF = []
for j in F:
    bpF.append(v.addVar(name = "bpF%d" % j))

blF = []
for j in F:
    blF.append(v.addVar(name = "blF%d" % j))

bpW = []
for k in W:
    bpW.append(v.addVar(name = "bpW%d" % k))

blW = []
for k in W:
    blW.append(v.addVar(name = "blW%d" % k))

v.modelSense = GRB.MAXIMIZE
v.update()

# Objective function:
v.setObjective(quicksum(n[i]*bpC[i] - blC[i] for i in C) + quicksum(m[j]*bpF[j] - blF[j] for j in F) + quicksum(r[k]*bpW[k] - blW[k] for k in W))

# Constraints:
for i in C:
v.addConstr(
    bpC[i] - blC[i] == quicksum(tp[i][j] - a[i][j]*x[i][j] for j in F) - (c[i] + PC[i])*g[i], "Profits in C%d" % i)
for j in F:
v.addConstr(
    bpF[j] - blF[j] == quicksum(t[j][k] - b[j][k]*y[j][k] for k in W) - e[j]*h[j] - quicksum(tp[i][j] for i in C), "Profits in F%d" % j)
for k in W:
v.addConstr(
    bpW[k] - blW[k] == s[k]*quicksum(y[j][k] for j in F) - quicksum(t[j][k] for j in F), "Profits in W%d" % k)
for i in C:
    v.addConstr(
        g[i] == QC[i], "Production in C%d" % i)
for j in F:
    v.addConstr(
        h[j] == QF[j], "Production in F%d" % j)
for i in C:
    quicksum(x[i][j] for j in F) - g[i] == 0, "Capacity of C%d" % i)
for j in F:
    quicksum(y[j][k] for k in W) - h[j] == 0, "Capacity of F%d" % j)
for j in F:
    x[0][j] + x[1][j] - quicksum(y[j][k] for k in W) == 0, "Component1 to F%d" % j)
for j in F:
    x[2][j] + x[3][j] - quicksum(y[j][k] for k in W) == 0, "Component2 to F%d" % j)
for k in W:
    quicksum(y[j][k] for j in F) == D[k], "Demand%d" % k)
for i in C:
    for j in F:
        v.addConstr(
            lbC[i][j]*x[i][j] <= tp[i][j], "LBC%d.%d" % (i, j))
for i in C:
    for j in F:
        v.addConstr(
            tp[i][j] <= ubC[i][j]*x[i][j], "UBC%d.%d" % (i, j))
for j in F:
    for k in W:
        v.addConstr(
            lbF[j][k]*y[j][k] <= t[j][k], "LBF%d.%d" % (j, k))
for j in F:
    for k in W:
        v.addConstr(
            t[j][k] <= ubF[j][k]*y[j][k], "UBF%d.%d" % (j, k))
# Solve:
v.optimize()
# Show solution in gurobi:
print(‘PROFITS: %g’ % v.objVal)
for i in C:
    print(' Produce %g units in C%s' %
        (g[i].x, i))
for i in C:
    for j in F:
        print(' Transport %g units from C%s to F%s' %
            (x[i][j].x, i, j))
for j in F:
    print(' Produce %g units in F%s' %
        (h[j].x, j))
for j in F:
    for k in W:
        print(' Transport %g units of final product from F%s to W%s' %
            (y[j][k].x, j, k))
for i in C:
    for j in F:
        print(' Transfer Price of components: %g paid to C%s from F%s' %
            (tp[i][j].x, i, j))
for j in F:
    for k in W:
        print(' Transfer Price of final product: %g paid to F%s from W%s' %
            (t[j][k].x, j, k))
for i in C:
    print(' %g profit in C%s' %
        (bpC[i].x, i))
for i in C:
    print(' %g loss in C%s' %
        (blC[i].x, i))
for j in F:
    print(' %g profit in F%s' %
        (bpF[j].x, j))
for j in F:
    print(' %g loss in F%s' %
        (blF[j].x, j))
for k in W:
    print(' %g profit in W%s' %
        (bpW[k].x, k))
for k in W:
    print(' %g loss in W%s' %
        (blW[k].x, k))
raw_input()
Optimize a model with 58 rows, 52 columns and 180 nonzeros
Found heuristic solution: objective -0
Presolve removed 10 rows and 12 columns
Presolve time: 0.00s
Presolved: 48 rows, 40 columns, 160 nonzeros
Variable types: 25 continuous, 15 integer (0 binary)

Root relaxation: objective 6.749541e+03, 31 iterations, 0.00 seconds

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Current Node</th>
<th>Objective Bounds</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expl Unexpl</td>
<td>Obj Depth IntInf</td>
<td>Incumbent BestBd Gap</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0 6749.54054</td>
<td>5 -0.00000 6749.54054</td>
</tr>
<tr>
<td>H</td>
<td>0</td>
<td>0 6749.0500000</td>
<td>6749.54054</td>
</tr>
</tbody>
</table>

Explored 0 nodes (31 simplex iterations) in 0.00 seconds
Thread count was 8 (of 8 available processors)

Optimal solution found (tolerance 1.00e-04)
Best objective 6.749050000000e+03, best bound 6.749540540541e+03, gap 0.0073%

TOTAL PROFITS: 6749.05
  Produce 110 units in C0
  Produce 200 units in C1
  Produce 110 units in C2
  Produce 200 units in C3
  Transport 110 units from C0 to F0
  Transport 0 units from C0 to F1
  Transport 37 units from C1 to F0
  Transport 163 units from C1 to F1
  Transport 110 units from C2 to F0
  Transport 0 units from C2 to F1
  Transport 37 units from C3 to F0
  Transport 163 units from C3 to F1
  Produce 147 units in F0
  Produce 163 units in F1
Transport 120 units of final product from F0 to W0
Transport 27 units of final product from F0 to W1
Transport 0 units of final product from F0 to W2
Transport 0 units of final product from F1 to W0
Transport 73 units of final product from F1 to W1
Transport 90 units of final product from F1 to W2
Transfer Price of components: 1760 paid to C0 from F0
Transfer Price of components: 0 paid to C0 from F1
Transfer Price of components: 1295 paid to C1 from F0
Transfer Price of components: 3097 paid to C1 from F1
Transfer Price of components: 3960 paid to C2 from F0
Transfer Price of components: 0 paid to C2 from F1
Transfer Price of components: 1332 paid to C3 from F0
Transfer Price of components: 1793 paid to C3 from F1
Transfer Price of final product: 9589 paid to F0 from W0
Transfer Price of final product: 1701 paid to F0 from W1
Transfer Price of final product: 0 paid to F0 from W2
Transfer Price of final product: 0 paid to F1 from W0
Transfer Price of final product: 6059 paid to F1 from W1
Transfer Price of final product: 7920 paid to F1 from W2
0 profit in C0
666 profit in C1
1880 profit in C2
666 profit in C3
0 loss in C0
0 loss in C1
0 loss in C2
0 loss in C3
0 profit in F0
4053 profit in F1
0 loss in F0
0 loss in F1
11 profit in W0
540 profit in W1
0 profit in W2
0 loss in W0
0 loss in W1
0 loss in W2
Table 6.1: Comparison between models

<table>
<thead>
<tr>
<th>Variables</th>
<th>TP Variable</th>
<th>TP Fixed</th>
<th>Without TP</th>
<th>TP = lower bound</th>
<th>TP = upper bound</th>
</tr>
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